

THE REVIEW OF A RESEARCH PROPOSAL TO STUDY  
THE EFFECTS OF 130 TORR OXYGEN ON SUBMARINERS

HELD AT THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY  
4 SEP 1986

Douglas R. Knight and Arthur B. Callahan, editors

NSMRL Memo Report 87-1

Approved and Released by:

*C. A. Harvey*

C. A. Harvey, CAPT, MC, USN  
Commanding Officer  
Naval Submarine Medical Research Laboratory

29 January 1987



## CONTENTS

|   | Page |
|---|------|
| Fleet Applications (LT Upchurch) . . . . .          | 1    |
| Research Design (CAPT Knight) . . . . .             | 2    |
| USARIEM's Altitude Chamber (Dr. Cymerman) . . . . . | 3    |
| Army Applications (Dr. Cymerman) . . . . .          | 4    |
| Proposed Measurements . . . . .                     | 4    |
| Discussion of Proposed Tests . . . . .              | 4    |
| Discussion of Experimental Design . . . . .         | 5    |
| SUMMARY (Dr. DuBois) . . . . .                      | 6    |
| Addendum- A Followup to the Meeting . . . . .       | 7    |



## EXECUTIVE SUMMARY

Scientists at the Naval Submarine Medical Research Laboratory and the U.S. Army Research Institute of Environmental Medicine have agreed to collaborate in studying the effects of oxygen-lean atmospheres on human performance. The design of that study is critically reviewed in this report.

ACKNOWLEDGEMENT: The editors wish to thank Professor Arthur B. DuBois, of the John B. Pierce Research Foundation, for chairing the scientific review.



## PROCEEDINGS

Fleet Applications (LT Upchurch). The extinguishment of fires aboard patrolling submarines relies on crew action and speed of response. Therefore, anything that slows the growth of fires will assist crews in bringing fires under control. Submarines routinely operate with oxygen concentrations close to 19%. This provides crews some protection from fires, since it is believed that 19%  $O_2$  reduces the rate of flame spread by one third when compared to the maximum allowed oxygen level of 21%. Unfortunately, further reductions of  $O_2$  concentration make it difficult to maintain the composition of submarine air within specified limits.

The Officer of the Deck is responsible for maintaining the partial pressure of oxygen ( $P_{O_2}$ ) at 140-160 torr while the barometric pressure ( $P_B$ ) is 700-800 torr, provided the oxygen concentration never exceeds 21% (figure 1). He does this by "bleeding"  $O_2$  into the atmosphere from storage banks. Reductions of  $P_{O_2}$  occur when there is an increase in crew activity, venting, or operation of the high-pressure air compressors. It is usually possible to maintain the  $P_{O_2}$  within  $\pm 5$  torr of the desired level, but there are instances when  $P_{O_2}$  drops to lower values. It is harder to maintain  $P_{O_2} > 140$  torr when  $P_B \leq 740$  torr (figure 1). If the lower limit of  $P_{O_2}$  were reduced to 130 torr, the Officer of the Deck could maintain 19% oxygen, as an average concentration, without concern for slipping below the current limit of 140 torr.

The other method of reducing  $O_2$  concentration is to raise  $P_B$  of the atmosphere by the addition of hyperbaric nitrogen. There are design limitations which preclude the use of this technique on a routine basis. Sufficient high-pressure air must always be available to make an emergency ascent to the surface. Yet the air banks reserved for emergency ascent also support other engineering needs, such as operation of various valves. A gradual rise of  $P_B$  results when air-operated equipment leaks into the atmosphere. At some point, air must be compressed from the atmosphere back into the high-pressure tanks. An extra set of air banks would have to be installed in order to maintain a hyperbaric atmosphere. The current practice of snorkeling would preclude the maintenance of hyperbaric pressure, but there are instances when submarines abstain from snorkeling for long periods of time. There may also be a problem with injury to the ears by the excursions of  $P_B$ .

The snorkeling procedure is used for training, drills, and emergency procedures. The loss of electrical power requires snorkeling for operation of the diesel engine. The diesel's air intake is fed by atmospheric gas that is ultimately derived from the fan room. Outside air enters the ship's fan room through the snorkel mast. Since the air inlet is of large diameter, flooding of the ship is prevented by the action of solenoid valves in the snorkel head valve. Closure of the head valve allows a significant partial vacuum to develop in the ship, as the diesel engine

does not immediately shut down. There may be a prolonged closure of the head valve during "sink-out", when the ship is trimmed too heavily at periscope depth. The diesel will continue to draw air from the atmosphere until manually shut down, or automatically shuts down at a partial vacuum of about 5 inches mercury (ca. 630 torr). Diesel engines generally shutdown by the time  $P_B$  drops to 700 torr; but more data are needed to confirm this impression.

In summary, The SUBMARINE FIRE SAFETY COMMITTEE would like biomedical scientists to validate the use of lower  $P_{O_2}$ 's aboard nuclear submarines. To do this, specific information is needed regarding human tolerance for living in the cross hatched area (figure 1) of an expanded oxygen zone. In order to minimize the chances of a fire, the COMMITTEE wishes to encourage submarine commanders to operate with oxygen concentrations below 19% by publishing the idea in the atmosphere control manual.

Research Design (CAPT Knight). Sea-level residents are accustomed to working in 21% oxygen (160 torr  $O_2$ -600 torr  $N_2$ ). Reductions of oxygen concentration interfere with thermal decomposition and aerobic metabolism, resulting in suppression of fires and impairment of human performance. But, human activity need not suffer from hypoxia if physiologically acceptable  $P_{O_2}$ 's are maintained by a life-support system. Man could perform quite effectively when breathing 11% oxygen at  $P_{O_2}$  130 torr, if the life-support system used hyperbaric nitrogen to maintain barometric pressure at 1182 torr (equation 1).

$$(1.) \%O_2 = 100(P_{O_2}/P_B)$$

Industrial activities flourish in nitrogen-based atmospheres containing 130 torr oxygen. For example, the residents of Denver are quite productive in performing skilled tasks and sustaining their community. The same is true of Air Force Crews operating at cabin altitudes of 5,000-8,000 ft. Therefore, it's reasonable to suspect that submariners could successfully operate with similar deficiencies of oxygen.

There are instances when the artificial atmosphere of a submarine must be exchanged with Earth's natural atmosphere. If the submarine atmosphere is hyperbaric, sudden reduction of the ship's internal pressure to sea-level will diminish the crew's  $P_{O_2}$ . During snorkeling, the diesel engine can create a partial vacuum in the ship during closure of the head valve. In the worst case,  $P_{O_2}$  could drop to 95-100 torr.

PROPOSAL. Before the Naval Medical Command sanctions the lowering of  $P_{O_2}$  to 130 torr, experiments must demonstrate that crews can effectively perform their duties in the unique environment of a nuclear submarine. Before conducting sea-trials, we wish to document the responses of submariners to an oxygen-deficient environment. The submarine atmosphere will be simulated by contaminating the atmosphere of a hypobaric chamber with 10 ppm carbon monoxide and 0.9% carbon dioxide. According to shipboard practice, the subjects will live an 18-hour day that is divided



into 6 hours of sleep and 12 hours of activity. Different groups of 11 men will be exposed to  $P_{O_2}$ 's of 160, 130, and 100 torr at sea-level pressure (figure 2). This means the groups will breathe 21%, 17%, and 13% oxygen. Accidental, prolonged operation of the diesel engine during closure of the head valve will be simulated by superimposing a 6-hour reduction of barometric pressure to 576 torr on the group exposed to 17% oxygen. Five days will be spent in training the subjects for their 8-day exposure. An additional 1.5 days will be used to observe their recovery.

[Discussion. The effects of confinement and changes of circadian rhythms would be controlled by the exposure to 21% oxygen. There is a potential problem with using smokers, since performance may be altered as a function of withdrawal rather than hypoxia. The simulation of a partial vacuum may cause some subjects to develop acute mountain sickness in less than 6 hours.]

USARIEM's Altitude Chamber (Dr. Cymerman). The 12-man altitude chamber has been in operation since 1966 and currently supports 2000 man-hours of experimentation per year. It is designed to maintain a constant environment over a long period of time (eg 7 weeks) and supports test procedures as elaborate as cardiac catheterization. Low pressures are maintained by the Venturi principle. Subjects usually live in the 2200 ft<sup>3</sup> room (20 X 30 ft), conduct personal hygiene in the air lock (500 ft<sup>3</sup>), and perform tests in the 1100 ft<sup>3</sup> room (9 X 10 ft). There is one pass-through in each room. Fire extinguishers are located inside the chamber. The climate is controlled within the following limits: 0-50,000 ft simulated altitude; 20-80  $\pm$  5% rh; and -20-110 °F. The air masks vent to the chamber atmosphere. The chamber is operated by 3 trained technicians that work in 8-hour shifts. A medical aid room is located near the chamber.

A control system is being installed for the purpose of maintaining concentrations of oxygen, carbon dioxide, and carbon monoxide within levels required for this study. The performance of the system will be tested in December, 1986.

There are two problems with exposing 11 subjects for 8 days. First, Army bunks will only permit sleeping accommodations for 8 subjects in the 2200 ft<sup>3</sup> room. The use of 11-12 subjects would diminish the floor space per man to unacceptable crowding. Second, frequent entry through the air lock will make it difficult to control the atmosphere's composition. For this reason, it's important to know how many investigators will enter the chamber and how frequently.

[Discussions. Three tiered bunks could be used for sleeping accommodations. The number of investigators entering the chamber could be reduced by training the subjects to perform their own testing. The lock's atmosphere could be isolated until it approximates that of the subjects' atmosphere. Also, a barrier could be placed outside of the lock to diminish convective mixing of outside air with that of the chamber atmosphere.]

Army Applications (Dr. Cymerman). USARIEM scientists have never studied normobaric hypoxia. The proposed exposure to  $P_{O_2}$  95-100 torr, by simulated snorkeling (figure 2), should cause headaches<sup>2</sup> within 4 hours. But "staging", by exposure to normobaric  $P_{O_2}$  130 torr, could protect men from acute mountain sickness resulting from rapid ascent to a simulated altitude of  $P_{O_2}$  95-100 torr.

Proposed Measurements. Group discussion suggested that procedural tests (eg timed performance of memorized tasks) are resistant to hypoxia, but decision making is susceptible to hypoxia. Submariners commonly encounter new problems requiring mathematical solutions during ships' operations.

VISION. Scotopic vision and field-of-vision may change in  $P_{O_2}$  100 torr. Scotopic vision will be measured in a dark room by asking<sup>2</sup> the subject to report his detection of a low-intensity, pin-point light. The field-of-vision test will be performed in the 0-180° meridian using colored LED's. The LED's will detect visual sensitivity to red, white, and green, since these are the important colors for periscope operators.

MENTAL PERFORMANCE. NSMRL's battery of psychomotor performance tests seem appropriate for use, since they are sensitive to nitrogen narcosis and cannot be memorized. All tests will be administered to resting subjects. Select tests will be administered while the subjects exercise for 20 minutes at 65% of their maximum capacity. Maximum capacity is defined as the peak work load achieved while breathing 160 torr oxygen. Before, during and after exercise, the subjects will rate their perceived level of exertion.

HEALTH AND MENTAL STATUS. Each subject will be questioned periodically about his mood and perception of health. Moods are not expected to change at 130 torr, but may change at  $P_{O_2}$  100 torr. The changes of mood are expected to be transient and could<sup>2</sup> disappear after 24-36 hours of exposure to hypoxia. An environmental symptoms questionnaire will be used to evaluate any symptoms of mountain sickness reported by the subjects. The questionnaire has been validated by field use at Pike's Peak.

Measurements of serum enzymes have been selected to screen for liver damage. Alveolar and arterial gases will be measured to document changes of oxygen stores in the body.

Discussion of Proposed Tests. The amount of time for experimentation could be a problem since 11 subjects will require at least one hour per investigation. Subject motivation is another factor potentially affecting the test scores.

Would two weeks of exposure uncover symptoms of mountain sickness that might otherwise be missed using shorter exposures to  $P_{O_2}$  130 torr? Probably not since physicians at Denver have reported the effects of altitude to appear in the first few days of exposure.

Measurements of serum enzymes do not test the effect of hypoxia and atmosphere contaminants on the function of cytochrome P-450. This would best be approached by use of experimental animals such as the laboratory rat. The discomfort associated with sampling of arterial blood may cause the subject to hyperventilate. If so, the arterial oxygen content would not be an accurate index of oxygen stores in blood. It would be better to measure oxyhemoglobin saturation non-invasively and assume that alveolar  $P_{O_2}$  equals arterial  $P_{O_2}$ .

Discussion of Experimental Design. Some people respond differently to hypoxia. If there is wide variation of responses between subjects, eight may be too small a group for testing mental performance. The way to judge adequacy of sample size is to perform a power analysis. An alternative method would be to select subjects predisposed to hypoxia. For example, the Cherniack test requires a candidate to take 3 successive breaths of nitrogen before resuming ventilation with air. Individuals with insensitive carotid bodies, as judged by a weak hyperventilatory response to nitrogen, would be more susceptible to hypoxic deterioration of mental performance.

[Discussion then indicated that three Laboratories have been performing hypoxia sensitivity tests. To date, the results have been non-uniform.]

The double blind protocol will be very difficult to perform. For example, a decision must be made whether air masks will be routinely worn by the investigators. The masks dump air into the atmosphere, making it difficult to control the oxygen concentration. Yet, wearing of the masks during exposure to  $P_{O_2}$  100 torr would be informative to the investigators. Smoking may break the code since  $P_{O_2}$  100 torr is not expected to support flaming combustion.

Should different groups of subjects be used for each  $P_{O_2}$  (between-subjects design), or should the same group be used for all  $P_{O_2}$  (within-subjects design)?

FOR DIFFERENT GROUPS- Each person could serve as his own control by performing all tests during the baseline (training) period. In that case, it would seem advisable to conduct training in the chamber.

AGAINST DIFFERENT GROUPS- There may not be enough statistical power in the tests to show a statistical difference between small groups.

FOR SAME GROUP- A repeated-exposure design increases the statistical power of the tests, since the comparison is within subjects.

AGAINST SAME GROUP- Hypoxia may stimulate physiological responses which remain for some time after the subjects return to 160 torr oxygen. For example, 100 torr oxygen can stimulate erythropoiesis. This presents the problem of determining when de-adaptation is complete. Repetition of exposure provides the subject a learning experience that improves performance.

An alternative is to perform a severity study, in which  $P_{O_2}$  is dropped until the subjects show decrements of performance.

Do the subjects need to be submariners? Submariners are the target population for this research. They are a homogenous subpopulation of Naval personnel who share the attributes of good health, motivated service, and tolerance of confined spaces. On the other hand, it is not absolutely necessary to use submariners since divers and soldiers have successfully performed the proposed battery of psychological tests.

#### SUMMARY

There are good reasons for doing the collaborative study. The Navy would like to operate submarines with crews exposed to 19% oxygen. It is therefore desirable to reduce the permissible limit of  $P_{O_2}$  from 140 to 130 torr. Snorkeling rarely drops a ship's internal pressure below 700 torr, but accidental circumstances could create a partial vacuum of -5 inches mercury. The effects of reduced oxygen concentration and partial vacuums can be studied in an altitude chamber.

The selection of physiological and psychological tests is appropriate, except for collecting blood samples which attempt to measure arterial oxygen content and detect damage to organs such as the liver. The exposure time of 8 days is appropriate in the absence of data showing that longer exposures at 5,000 ft altitude cause delayed onset of mountain sickness.

Discussions uncovered the problem of using a within-subject versus between-subject design. Repetitive exposures of the same men to all conditions would increase the investigators' chances for observing changes of performance in relationship to ambient  $P_{O_2}$ . But improvement with practice might disguise an effect of hypoxia. The use of different men for each  $P_{O_2}$  would introduce the possibility that subject variability prevents observation of statistically significant effects.

It is difficult to design a field study until results of the chamber studies are known.

## ADDENDUM- A FOLLOWUP TO THE MEETING

Power analyses of within-subject designs were made of the proposed psychological tests. Dr. Banderet analyzed the results of an altitude chamber exposure to 4,200 m (13,800 ft) and 15°C. Measurements were taken at 1 and 4 hours after ascent. The subjects' scores at altitude were compared with their performance at sea-level. The order of presentation to both pressures was counterbalanced. The most sensitive data for each test were used in the power analysis calculations (generally the 4 hour measurements).

| <u>TEST</u>                          | <u>POWER ANALYSIS</u> |
|--------------------------------------|-----------------------|
| CLYDE MOOD SCALE                     | 11 SUBJECTS           |
| MULTIPLE ADJECTIVE AFFECT CHECKLIST  | 12 SUBJECTS           |
| ENVIRONMENTAL SYMPTOMS QUESTIONNAIRE | 7 SUBJECTS            |
| ADDITION                             | 12 SUBJECTS           |
| CODING                               | 6 SUBJECTS            |
| MAP-COMPASS                          | 20 SUBJECTS           |
| NUMBER COMPARISON                    | 6 SUBJECTS            |
| PATTERN RECOGNITION                  | 15 SUBJECTS           |
| TOWER                                | 50 SUBJECTS (index A) |
|                                      | 7 SUBJECTS (index B)  |

Dr. Rogers determined that  $\geq 14$  subjects were needed to achieve significant results ( $P < .05$ , 2-tailed test) from a MATH TEST, if the subjects were tested under conditions of hypoxia or nitrogen narcosis. His analysis was based on a power level of 0.8 and the standard deviation was  $\pm 5.5$ . He assumed a correlation of 0.6 and a mean difference of 3. More subjects would be needed to achieve significant results if a between-subjects design were used.

The power analyses suggested that at least 12 subjects be exposed to all levels of hypoxia by a within-subject design. Figure 3 depicts a mixed-design which exposes  $\geq 16$  subjects to 160, 130, and 100 torr oxygen. The design permits evaluation of the effect of a partial vacuum on crew performance. After 5-6 days of training (T), the subjects will live inside the altitude chamber for the entire period of time shown on the graph. Performance at  $P_{O_2}$  160 torr will be measured during the baseline (B), first-recovery ( $R_1$ ) and second-recovery ( $R_2$ ) periods. The durations of these periods equal the length of exposure periods ( $E_1, E_2$ ). Symptoms of hypoxia (ie, acute mountain sickness) should develop within 72 hours of oxygen deficiency; therefore, the times of exposure ( $E_1, E_2$ ) will be 72 hours plus time for breathe-down. Illness from hypoxia should disappear

within 1-3 days of returning to 160 torr oxygen. A partial vacuum will be imposed on the subjects at the end of exposure to 130 torr oxygen, which corresponds to event  $S_2$  for group A and  $S_3$  for group B (figure 3). The tests of tolerance for partial vacuum will be administered during events  $S_1$ ,  $S_2$ ,  $S_3$ , and  $S_4$  (figure 3).

The breathe-down time to 13% oxygen is estimated to be 33 hours aboard an SSN-578 class submarine, compared to 9 hours in USARIEM's hypobaric chamber.

There are 2 problems with using the mixed-design: First, the development of acute mountain sickness during one level of hypoxia may degrade performance in the next level of oxygen. Second, performance may improve as a function of experience at the task; yet there is no control exposure for the effect of experience. These problems seem to be manageable. First, recovery from the symptoms of acute mountain sickness should be accompanied by return of baseline mental function. Second, the effect of experience is assumed to be resistant to the levels of hypoxia imposed on the subjects.

A problem could arise from using the 18-hour day (see page 2), since the probable shift in circadian rhythm of body temperature could degrade human performance. Unless the effect of circadian rhythm is specifically controlled, a circadian effect could not be distinguished from a hypoxic effect.

## PARTICIPANTS

### CHAIRMAN

Dr. Arthur B. DuBois, MD  
Professor and Director  
John B. Pierce Research Foundation  
290 Congress Avenue  
New Haven, CT 06519  
(203)-562-9901

### SPEAKERS

LT Jeff Upchurch, USN  
Chmn, NAVSEA Submarine Fire Protection Committee  
Code 92D  
Naval Sea Systems Command  
Washington, DC 20362  
autovon 222-1566  
(202)-692-1566

Dr. Al Cymerman, Ph.D.  
Director, Altitude Research Division  
U.S. Army Research Institute of Environmental Medicine  
Natick, MA 01760  
(617) 651-4852  
autovon 256-4852

CAPT Douglas R. Knight, MC USN  
Dept of Biological Sciences  
Naval Submarine Medical Research Laboratory  
Submarine Base, New London  
Groton, CT 06349-5900  
(203)-449-2508  
autovon 241-2508

### DISCUSSANTS

Paul B. Rock, D.O., Ph.D.  
Major, Medical Corps, US Army  
Altitude Research Division  
U.S. Army Research Institute of Environmental Medicine  
Natick, MA 01760  
(617) 651-4802  
autovon 256-4802

Louis E. Banderet, Ph.D.  
Health and Performance Division  
U.S. Army Research Institute of Environmental Medicine  
Natick, MA 01760  
(617) 651-4850  
autovon 256-4850

Mr. James Devine  
Altitude Research Division  
U.S. Army Research Institute of Environmental Medicine  
Natick, MA 01760  
(617) 651-4820

Dr. Arthur B. Callahan, Ph.D.  
Director, Dept of Biological Sciences  
Naval Submarine Medical Research Laboratory  
Submarine Base, New London  
Groton, CT 06349-5900  
(203)-449-2539  
autovon 241-2539

Dr. Saul Luria, Ph.D.  
Director, Vision Dept  
Naval Submarine Medical Research Laboratory  
Submarine Base, New London  
Groton, CT 06349-5900  
(203)-449-2527  
autovon 241-2527

Dr. William Rogers, Ph.D.  
Behavioral Science Dept  
Naval Submarine Medical Research Laboratory  
Submarine Base, New London  
Groton, CT 06349-5900  
(203)-449-2521  
autovon 241-2521

Dr. Donald V. Tappan, Ph.D.  
Dept of Biological Sciences  
Naval Submarine Medical Research Laboratory  
Submarine Base, New London  
Groton, CT 06349-5900  
(203)-449-2515

LCDR Jeffry Bowman, MSC USN  
Dept of Biological Sciences  
Naval Submarine Medical Research Laboratory  
Submarine Base, New London  
Groton, CT 06349-5900  
(203)-449-3419

Mr. Arthur Messier, MS  
Dept of Biological Sciences  
Naval Submarine Medical Research Laboratory  
Submarine Base, New London  
Groton, CT 06349-5900  
(203)-449-2537



Mr. James Dougherty, MS  
Dept of Biological Sciences  
Naval Submarine Medical Research Laboratory  
Submarine Base, New London  
Groton, CT 06349-5900  
(203)-449-4680

Ms. Elly Heyder, MS  
Dept of Biological Sciences  
Naval Submarine Medical Research Laboratory  
Submarine Base, New London  
Groton, CT 06349-5900  
(203)-449-2511

HM1 Daniel Francis, USN  
Dept of Biological Sciences  
Naval Submarine Medical Research Laboratory  
Submarine Base, New London  
Groton, CT 06349-5900

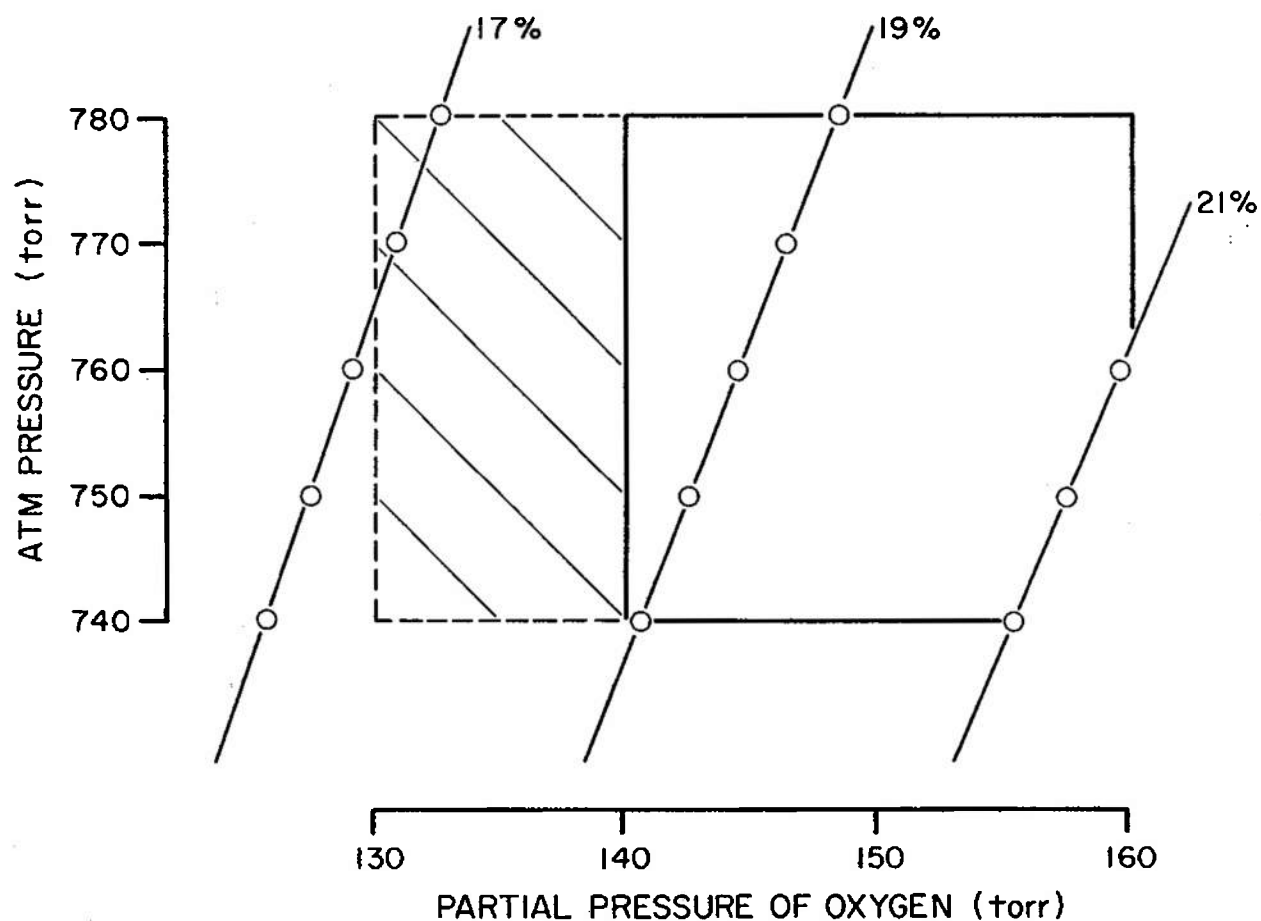


FIGURE 1. THE OXYGEN ZONE ABOARD SUBMARINES. Submarines currently operate with  $P_{O_2}$ 's of 140-160 torr (clear area of the figure). The objective of research is to determine if crews can operate effectively at  $P_{O_2}$ 's 130-140 torr (cross-hatched area of the figure).

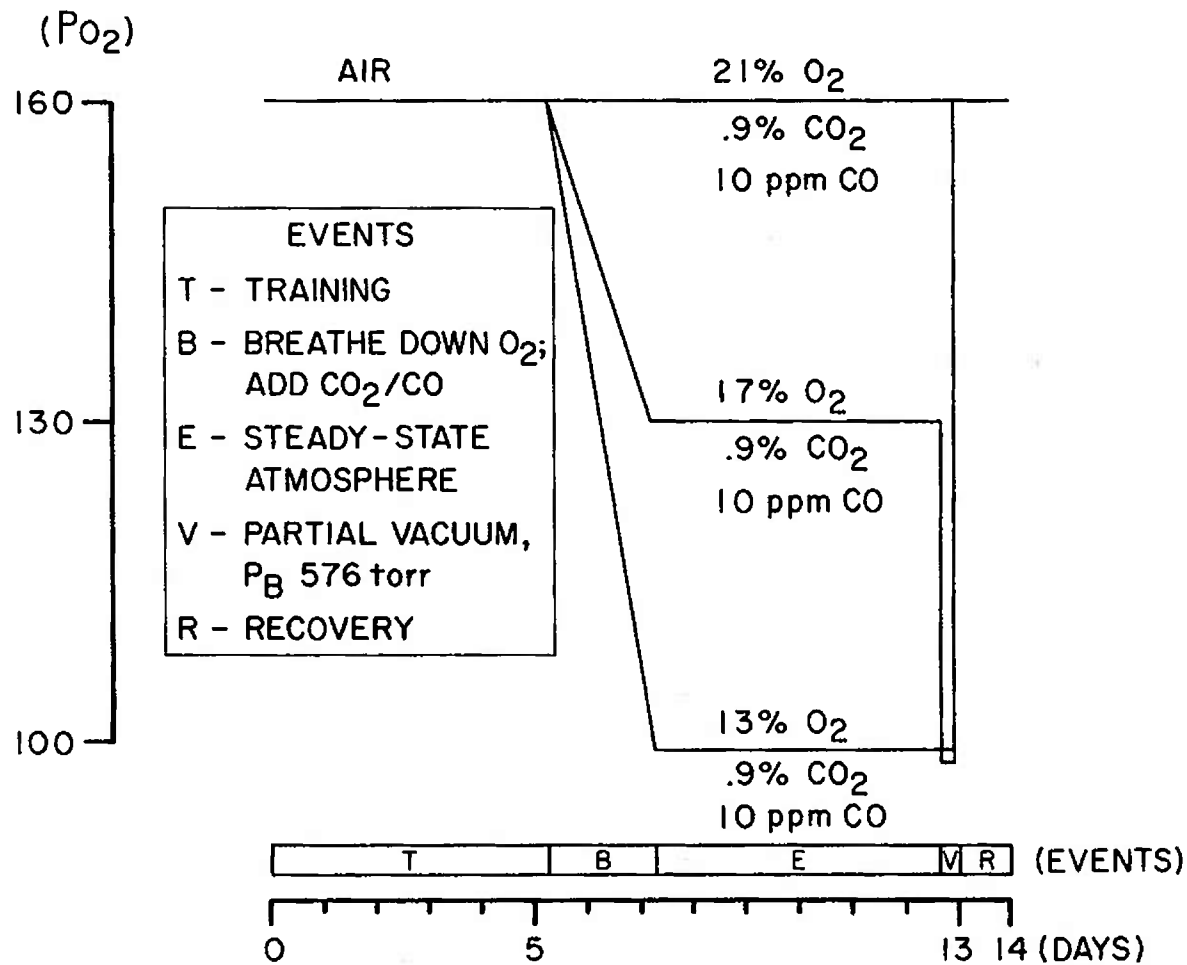


FIGURE 2. PROPOSED DESIGN FOR CHAMBER STUDIES. A different group of subjects would be exposed to each percentage of oxygen. The  $CO_2$  and CO routinely contaminate submarine atmospheres at the indicated concentrations.

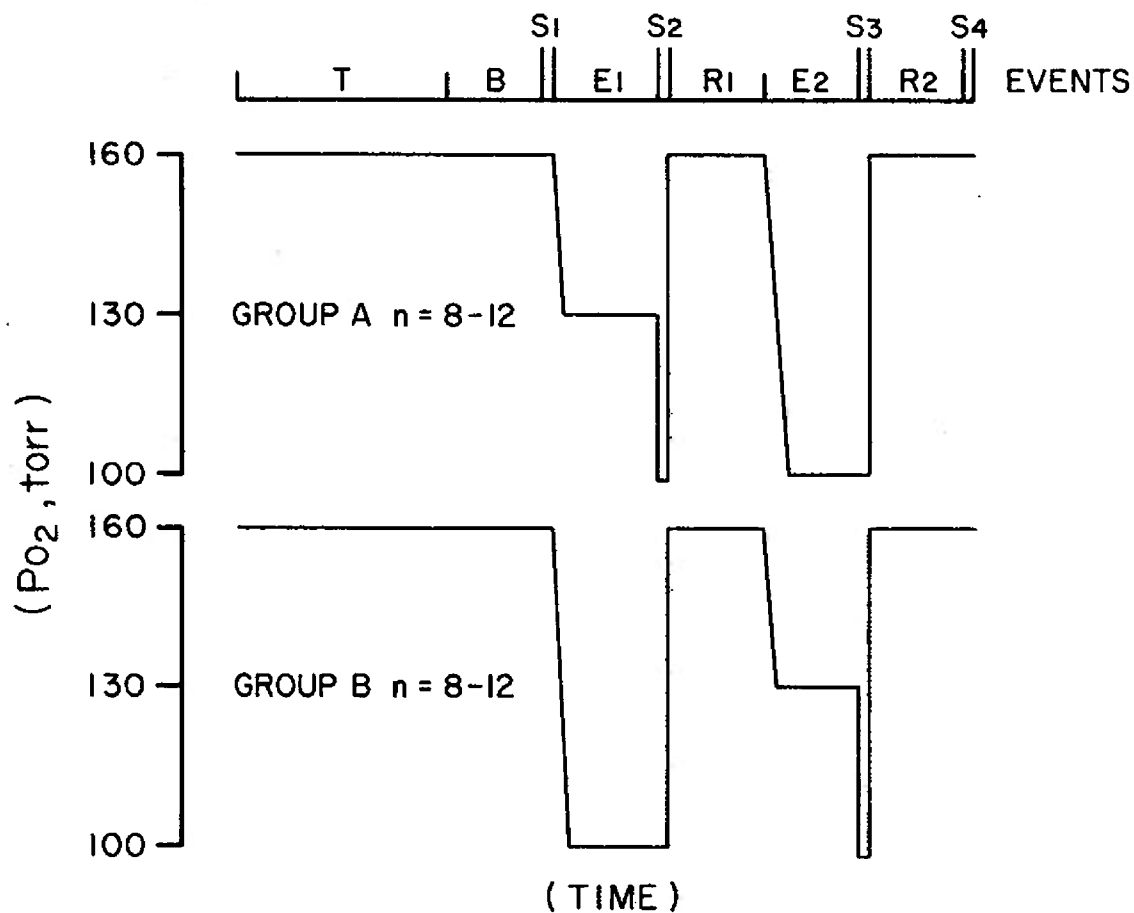


FIGURE 3. MODIFIED DESIGN FOR CHAMBER STUDIES. Two different groups of subjects would be exposed to the same partial pressures of oxygen. The same levels of CO and CO<sub>2</sub> contaminants would be used as indicated in figure 2. SYMBOLS for the events: T, training; B, baseline period; S, simulated partial vacuum; E, exposure; R, recovery.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE   |                       | READ INSTRUCTIONS<br>BEFORE COMPLETING FORM                  |
|---|-----------------------|--|
| 1. REPORT NUMBER  | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER                                |
| NSMRL Memo Report 87-1  |                       |  |
| 4. TITLE (and Subtitle)<br>A Review of a Research Proposal to Study the Effects of 130 Torr Oxygen on Submarines  |                       | 5. TYPE OF REPORT & PERIOD COVERED<br>Report of a review     |
| 7. AUTHOR(s)<br>D. R. Knight and A. B. Callahan, editors  |                       | 6. PERFORMING ORG. REPORT NUMBER<br>NSMRL Memo Rpt. No. 87-1 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Naval Submarine Medical Research Laboratory<br>Box 900 Naval Submarine Base New London<br>Groton, CT 06349-5900  |                       | 8. CONTRACT OR GRANT NUMBER(s)                               |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Naval Medical Rsch and Dev. Command<br>Naval Medical Command, National Capital Region  |                       | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS  |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)   |                       | 12. REPORT DATE<br>29 Jan 1987                               |
|   |                       | 13. NUMBER OF PAGES<br>14                                    |
|   |                       | 15. SECURITY CLASS. (of this report)<br>Unclassified         |
|   |                       | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE                   |
| 16. DISTRIBUTION STATEMENT (of this Report)<br>Approved for public release; distribution unlimited  |                       |  |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)  |                       |  |
| 18. SUPPLEMENTARY NOTES   |                       |  |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br>effects of oxygen-lean atmospheres; human performance   |                       |  |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><p>This review was held at NSMRL on 4 September 1986. Scientists at the laboratory and the U. S. Army Research Institute of Environmental Medicine have agreed to collaborate in studying the effects of oxygen-lean atmospheres on human performance. The design of that study is critically reviewed in this report.</p> |                       |  |

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE  
S/N 0102-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

